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(54) **TURBO DECODERS WITH EXTRINSIC ADDRESSING AND ASSOCIATED METHODS**

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H04L 1/00 (2006.01)

(52) **U.S. Cl.**
CPC **H04L 1/0071** (2013.01); **H03M 13/2957** (2013.01)

(58) **Field of Classification Search**
CPC H03M 13/2957
USPC 714/755, 762, 763, 792, 807
See application file for complete search history.

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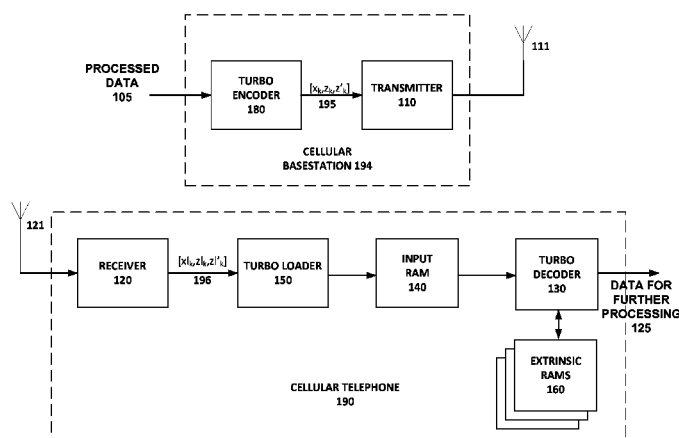
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Primary Examiner — Fritz Alphonse

(57) **ABSTRACT**

A plurality of turbo decoder engines store extrinsic values when concurrently decoding a received signal encoded within rows and columns of an interleaving matrix where interleaved values stay in a same re-ordered row during interleaving. An extrinsic reader and extrinsic writer accesses extrinsic memories using extrinsic addresses. A deinterleaver accesses the extrinsic addressable memories by arranging storage of the extrinsic values by the same rows of the same interleaving matrix that was used to encode the received signal, each of the rows corresponding to one of the plurality of turbo decoder engines, and, in embodiments, can group the extrinsic values such that all the extrinsic values in each one of the rows of the interleaving matrix go in a same one of the plurality of the extrinsic addressable memory. The deinterleaver can skip read of extrinsic values corresponding to dummy entries in the interleaving matrix.

20 Claims, 9 Drawing Sheets



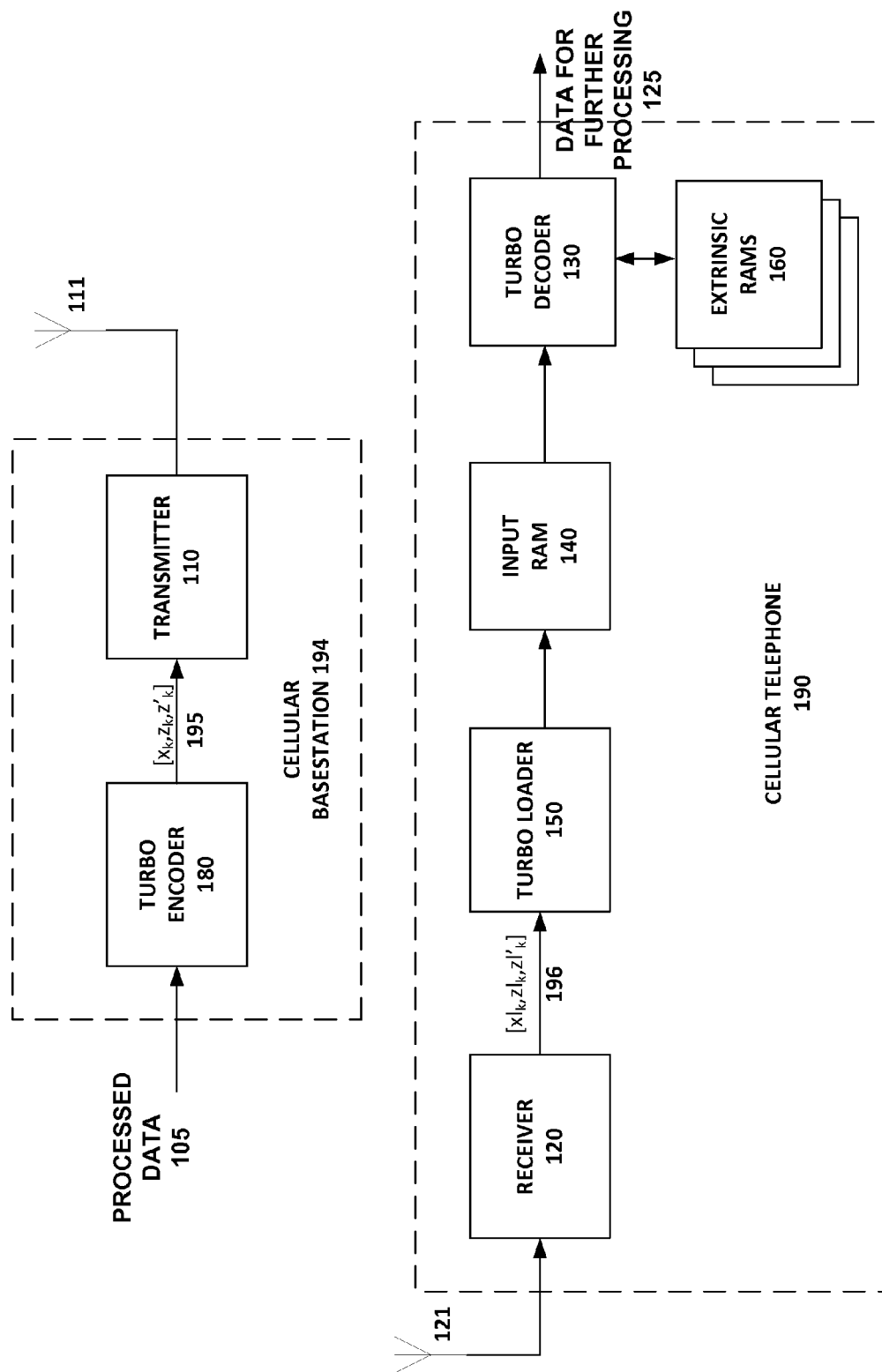


FIG. 1

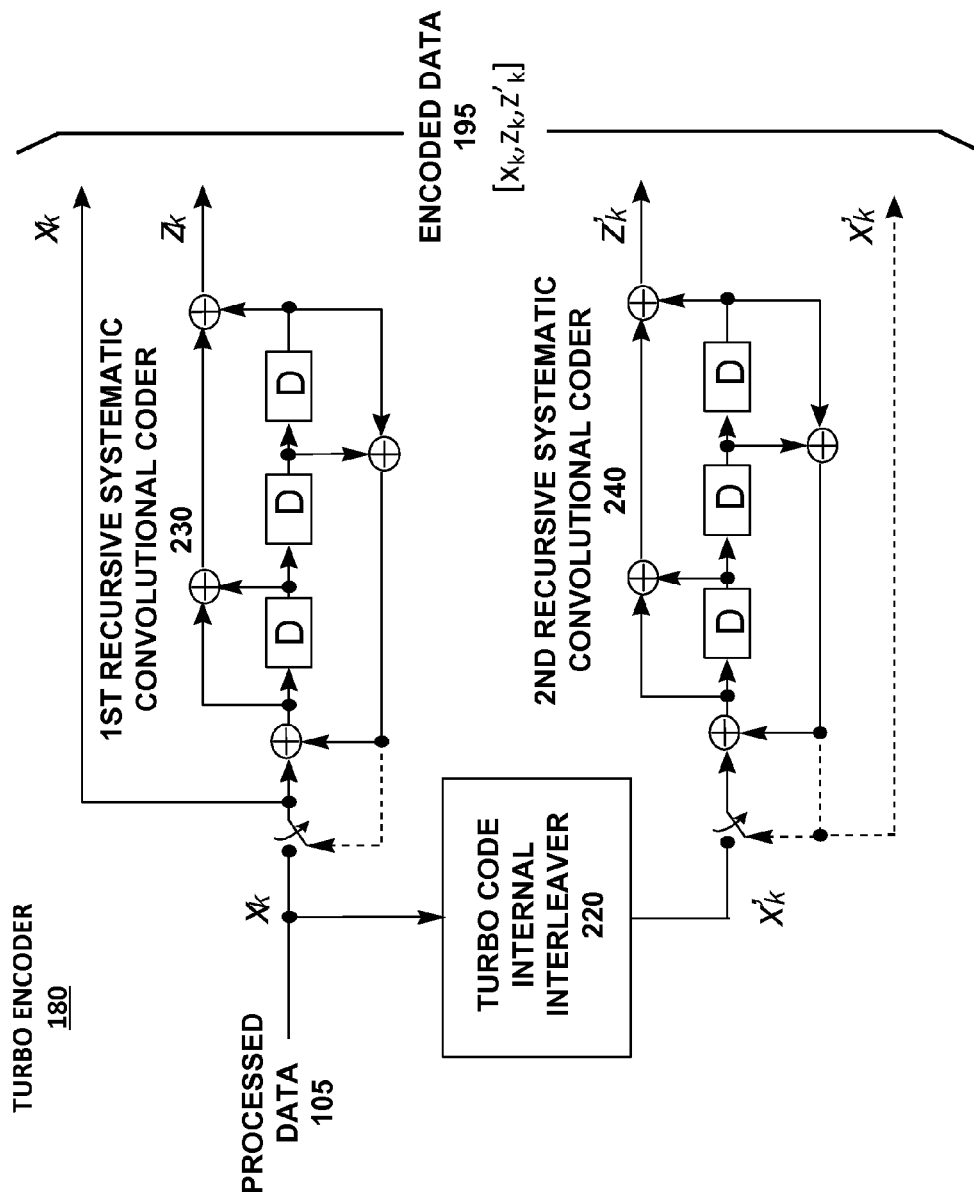


FIG. 2

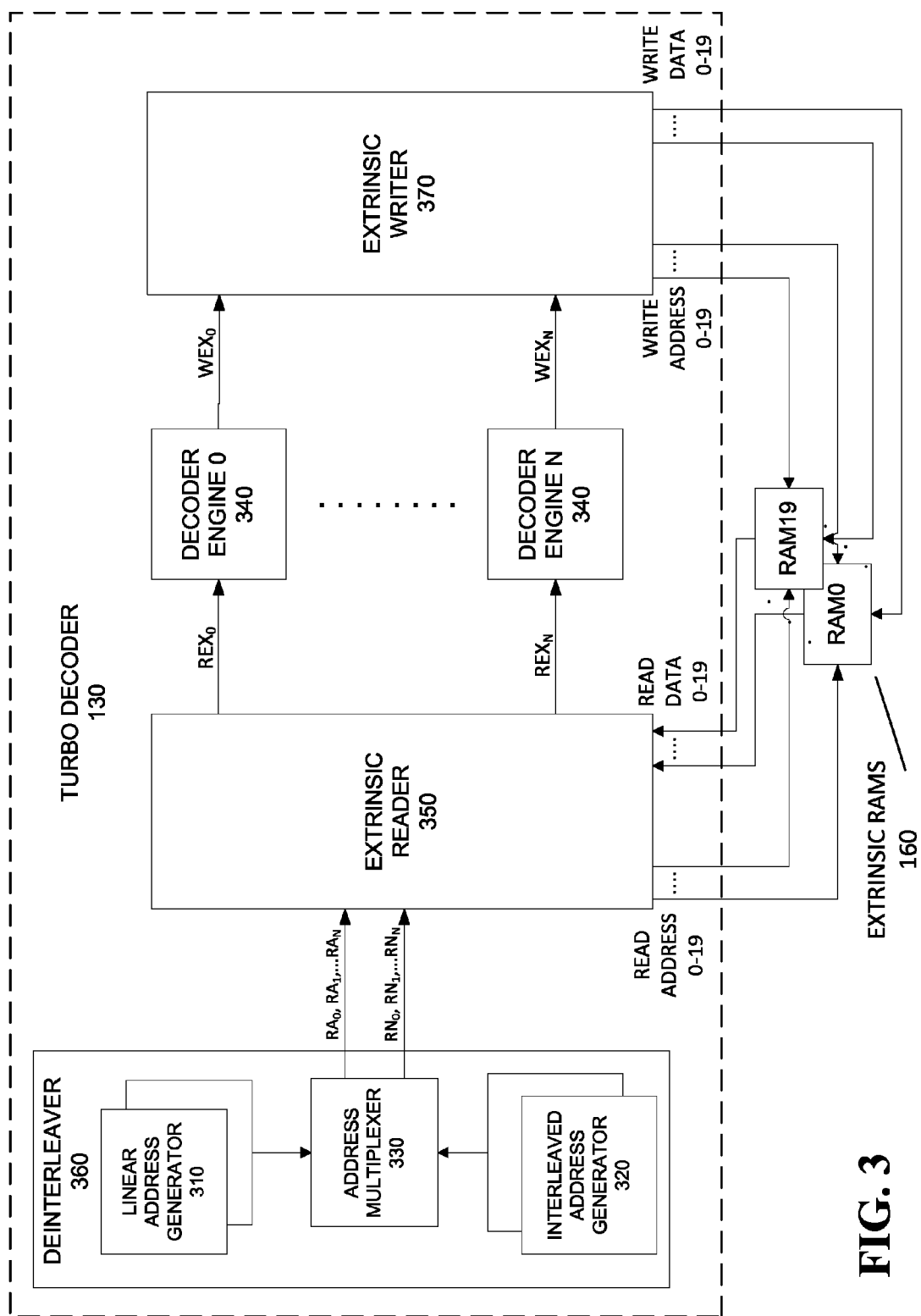


FIG. 3

Interleaving Process

| | 0 | 1 | 2 | . | . | . | 255 |
|----|------|------|------|---|---|---|------|
| 0 | 0 | 1 | 2 | . | . | . | 255 |
| 1 | 256 | 257 | 258 | . | . | . | 511 |
| 2 | 512 | 513 | 514 | . | . | . | 767 |
| 3 | 768 | 769 | 770 | . | . | . | 1024 |
| . | | . | . | . | . | . | |
| . | | . | . | . | . | . | |
| 19 | 4864 | 4865 | 4866 | . | . | . | 5119 |

LINEAR MATRIX 20X256

410

| | 0 | 1 | 2 | . | . | . | 255 |
|----|------|------|------|---|---|---|------|
| 0 | 4865 | 4866 | 5119 | . | . | . | 4864 |
| 1 | 0 | 255 | 2 | . | . | . | 1 |
| 2 | 1236 | 1278 | 1042 | . | . | . | 1114 |
| 3 | 2787 | 2648 | 2623 | . | . | . | 2297 |
| . | | . | . | . | . | . | |
| . | | . | . | . | . | . | |
| 19 | 511 | 257 | 258 | . | . | . | 256 |

INTERLEAVED MATRIX 20X256

420

FIG. 4

Extrinsic RAM Layout

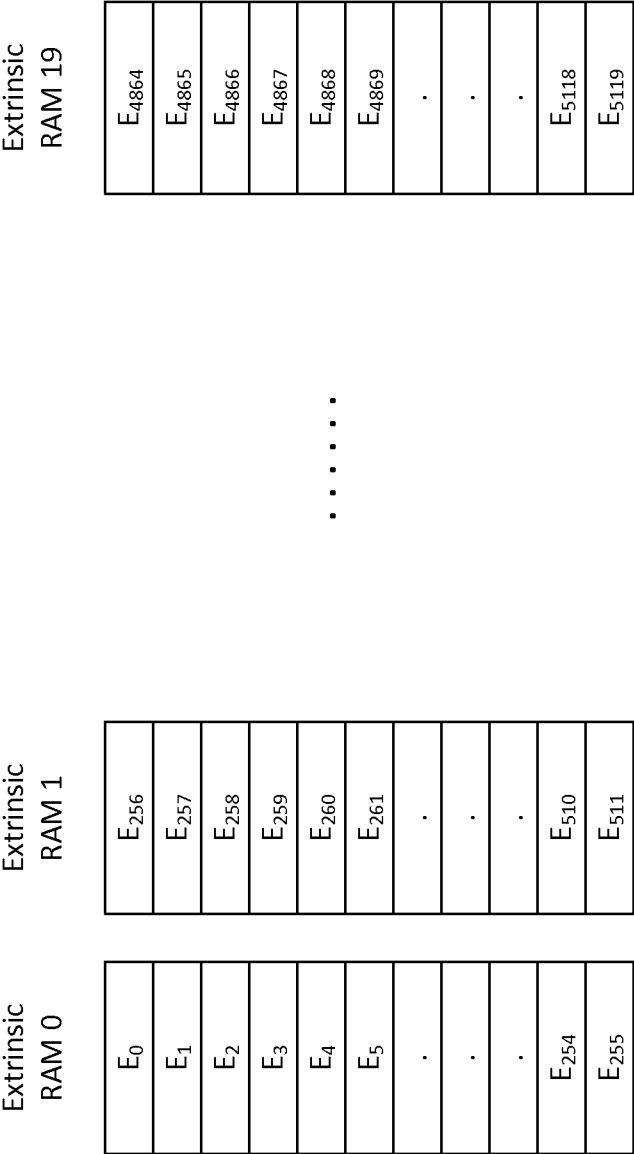


FIG. 5

De-Interleaver Extrinsic RAM Access Pattern For 2 Engines

| Linear MAP | | | | | | |
|------------|-----------------|-----------------|------------------|-----------------|-----------------|------------------|
| Cycle | Engine 0 | | | Engine 1 | | |
| | Row | Column | Extrinsic | Row | Column | Extrinsic |
| | RN ₀ | RA ₀ | REX ₀ | RN ₁ | RA ₁ | REX ₁ |
| 1 | 0 | 0 | E ₀ | 1 | 0 | E ₂₅₆ |
| 2 | 0 | 1 | E ₁ | 1 | 1 | E ₂₅₇ |
| 3 | 0 | 2 | E ₂ | 1 | 2 | E ₂₅₈ |
| | | | | | | |
| 255 | 0 | 254 | E ₂₅₄ | 1 | 254 | E ₅₁₀ |
| 256 | 0 | 255 | E ₂₅₅ | 1 | 255 | E ₅₁₁ |
| 257 | 2 | 0 | E ₅₁₂ | 3 | 0 | E ₇₆₈ |
| 258 | 2 | 1 | E ₅₁₃ | 3 | 1 | E ₇₆₉ |
| | | | | | | |

Skip over sub block
done by other
engine

FIG. 6

De-Interleaver Extrinsic RAM Access Pattern For 2 Engines

| Interleaved MAP | | | | | | | |
|-----------------|-----------------|-----------------|-------------------|-----------------|-----------------|-------------------|--|
| Engine 0 | | | | Engine 1 | | | |
| | Row | Column | Extrinsic | Row | Column | Extrinsic | |
| Cycle | RN ₀ | RA ₀ | REX ₀ | RN ₁ | RA ₁ | REX ₁ | |
| 1 | 0 | 0 | E ₄₈₆₅ | 1 | 1 | E ₂₅₅ | |
| 2 | 1 | 0 | E ₀ | 2 | 1 | E ₁₂₇₈ | |
| 3 | 2 | 0 | E ₁₂₃₆ | 3 | 1 | E ₂₆₄₈ | |
| | | | | | | | |
| 20 | 19 | 0 | E ₅₁₁ | 0 | 2 | E ₅₁₁₉ | |
| 21 | 0 | 1 | E ₄₈₆₆ | 1 | 2 | E ₂ | |
| 22 | 2 | 2 | E ₁₀₄₂ | 3 | 3 | E ₂₆₂₃ | |
| 23 | 3 | 2 | E ₂₆₂₃ | 4 | 3 | E ₄₁₂₂ | |
| | | | | | | | |

Skip over sub block
done by other
engine

FIG. 7

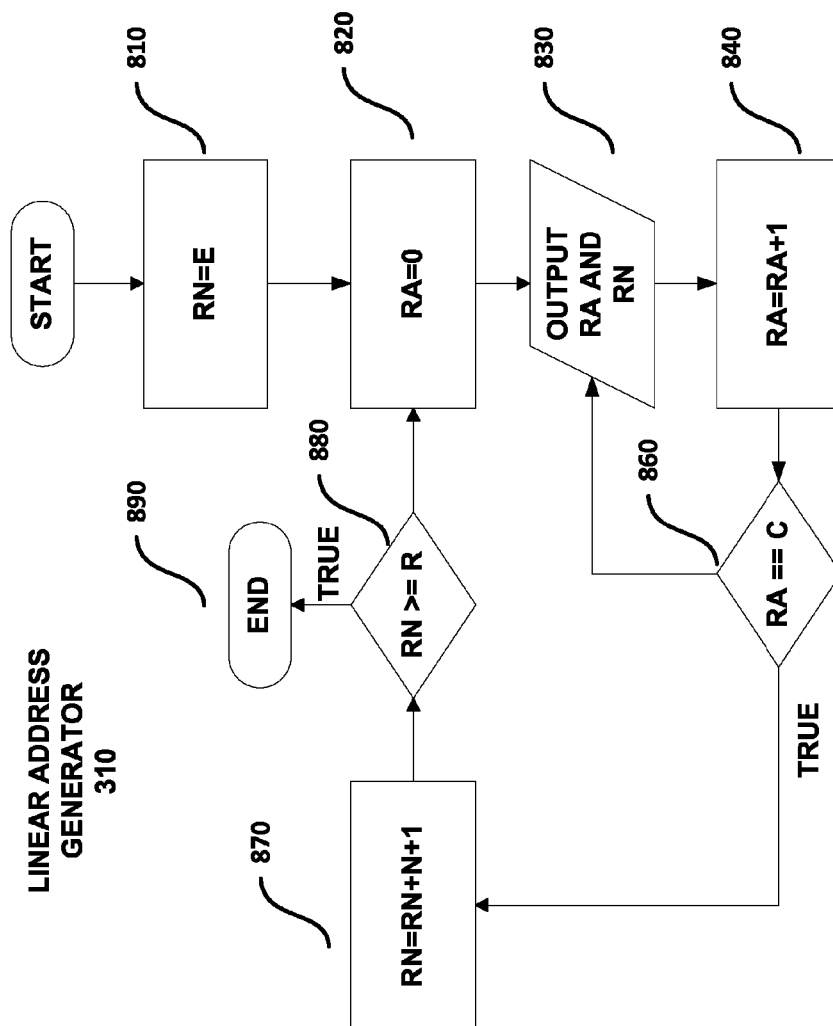


FIG. 8

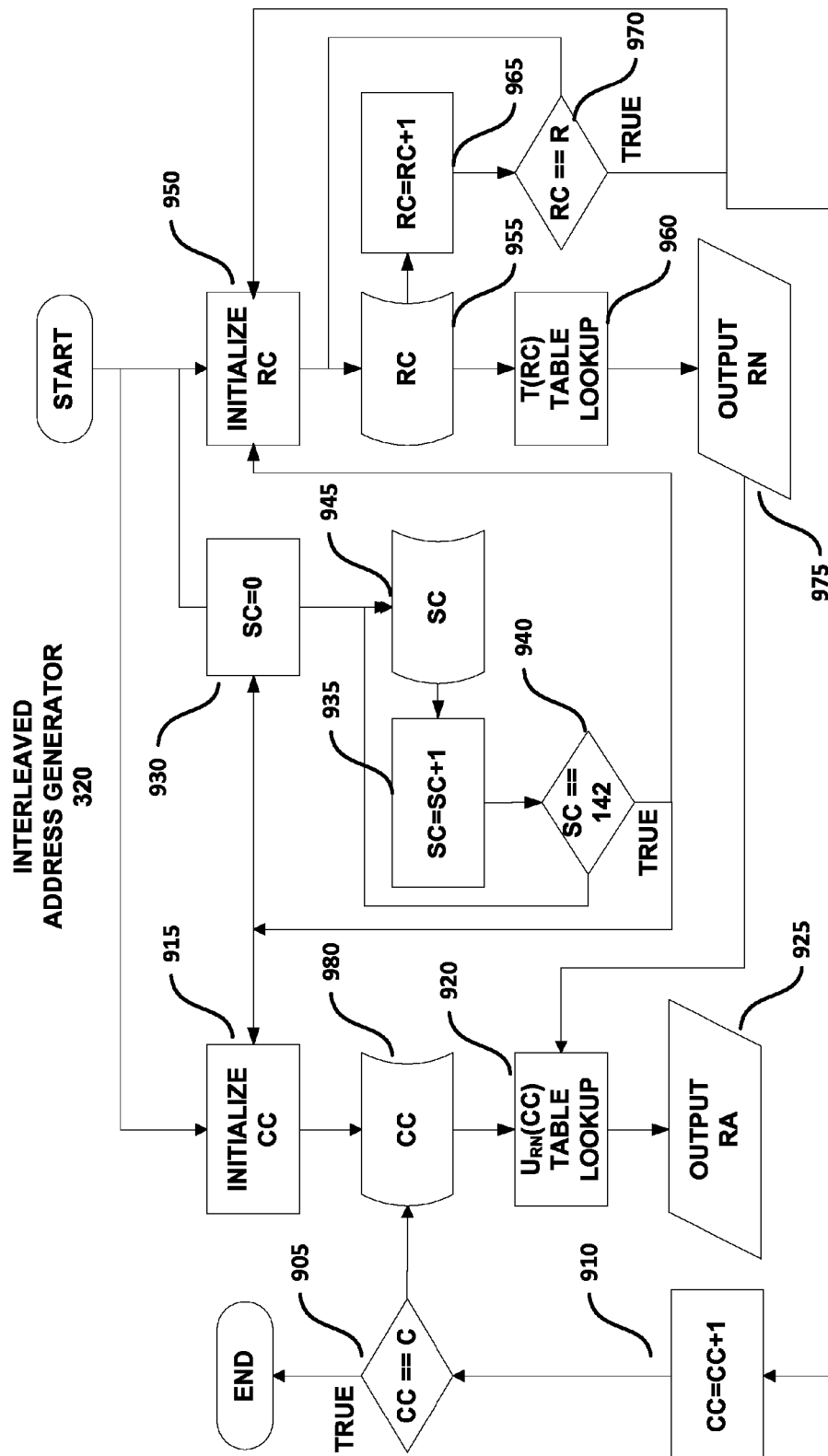


FIG. 9

TURBO DECODERS WITH EXTRINSIC ADDRESSING AND ASSOCIATED METHODS

BACKGROUND OF THE INVENTION

1. Technical Field

Embodiments of the present invention relate to turbo decoders and, more particularly, relate to avoiding memory conflict with a turbo decoder.

2. Description of the Related Art

Telecommunications involves sending information from a transmitter to a receiver. Channel coding is a process performed by the transmitter of adding extra information bits or redundant bits to the information to be sent. The receiver then uses the redundant bits to help it identify the sent message.

Typically signals are encoded before being sent to a cellular telephone using a method of encoding defined in a cellular standards specification. An encoder in the transmitter adds redundancy using a predetermined method and a decoder in the receiver uses knowledge of the redundancy method to increase reliability of data demodulation and decoding. Typically high latency sensitive traffic signals such as voice are encoded using a convolutional coder and lower latency sensitive traffic signals such as data are encoded using a turbo encoder. While cellular standards specifications specify the requirement for turbo encoding a signal, these cellular standards specifications do not typically specify the operations for turbo decoding a signal. Turbo decoding is basically defined as the reverse process of turbo encoding.

Turbo encoding is one method of encoding by adding redundancy. A turbo encoder uses an interleaver to shuffle the bits to be transmitted into a random order. The interleaving process increases the probability that errors introduced while the coded data is transmitted can be overcome and the original information reconstructed at the receiver.

A turbo decoder uses an iterative algorithm. For example, a turbo decoder may decode information using plural maximum a posteriori (MAP) estimates. The turbo decoder alternates between processing received samples relating to (x_k, z_k) called even MAP estimates, and processing received samples relating to z'_k called odd MAP estimates. The two MAP estimates are together called an iteration. For example, if the turbo decoder performs 4 iterations that means it would have processed 8 MAP estimates.

The turbo encoder and turbo decoder are an integral part of telecom standards with data rates reaching upwards of 100 Mbps (million bits per second). These high data rates create new demands on processing speed which require multiple bits to be processed in parallel. To achieve this, a parallel architecture of multiple decoder engines is used. There are two ways to decode in parallel. A first way is to break a coded block into smaller sub-blocks, and process those in parallel. A second way is to process multiple coded blocks in parallel. The first approach increases decoding latency and input random access memory (RAM) requirements. The second approach may have problems with memory conflicts.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention are illustrated by way of example and are not limited by the accompanying figures, in which like references indicate similar elements. Elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale.

The details of the various embodiments will be more readily understood from the following detailed description when read in conjunction with the accompanying drawings wherein:

FIG. 1 illustrates a schematic block diagram of an exemplary cellular base station and an exemplary cellular telephone according to an exemplary embodiment of the present invention;

FIG. 2 illustrates a schematic block diagram of an exemplary turbo encoder relating to embodiments of the present invention;

FIG. 3 illustrates a schematic block diagram of the turbo decoder and extrinsic RAMs according to an exemplary embodiment of the present invention;

FIG. 4 illustrates example matrices of the interleaving process according to an exemplary embodiment of the present invention;

FIG. 5 illustrates the extrinsic RAM layout for a typical case;

FIG. 6 illustrates the RAM access performed every cycle for a linear MAP;

FIG. 7 illustrates the RAM accesses performed every cycle for an interleaved MAP estimates;

FIG. 8 illustrates a flow diagram of the process performed by the linear address generator according to an exemplary embodiment of the present invention; and

FIG. 9 illustrates a flow diagram of the process performed by the interleaved address generator according to an exemplary embodiment of the present invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS

FIG. 1 illustrates a schematic block diagram of an exemplary cellular basestation **194** and an exemplary cellular telephone **190** according to an exemplary embodiment of the present invention. A turbo encoder **180** and transmitter **110** are in the cellular basestation **194** coupled to an associated antenna **111**. The turbo encoder **180** sends encoded data $[x_k, z_k, z'_k]$ to the transmitter **110**.

The cellular basestation **194** takes in voice or internet data and processes it. After some processing, the processed data **105** is sent to the turbo encoder **180**. The turbo encoder **180** takes input bits x_k , and adds redundant information. A predetermined interleaving sequence is used to derive this redundant information. Both the encoder and the decoder are preprogrammed according to an agreed upon specification standard with the same predetermined interleaving sequence. This redundant information is labeled z_k and z'_k , and shown in FIG. 2. The redundant information is added to the output of an encoder in order to help the decoder correct errors in the data x_k . The data and redundant information $[x_k, z_k, z'_k]$ go through the transmitter **110** and over the air to the receiver **120**.

A radio receiver **120**, a turbo loader **150**, input RAM **140**, a turbo decoder **130**, and a plurality of extrinsic RAMs **160** are in the cellular telephone **190** coupled to an associated antenna **121**. While a random access memory is one preferred embodiment for the input RAM **140** and the extrinsic RAMs **160**, any extrinsic addressable memory can be used such as flash or latches or flip flops.

The radio receiver **120** and antenna **121** can be typical of that used in a portable cellular telephone **190** or other mobile cellular radio device. The receiver **120** demodulates a received signal and may descramble the signal depending on the cellular standards specification needed. Next the received signal is decoded. Depending on the type of signal

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received, a turbo loader **150** and a turbo decoder **130** are used to decode the demodulated received signal.

After transmission of the encoded data $[x_{k'}, z_{k'}, z'_{k'}]$ **195** by the transmitter **110** via the antenna **111**, received encoded data $[x_{1_{k'}}, z_{1_{k'}}, z'_{1_{k'}}]$ **196** is initially received by the receiver **120** and written into the input RAM **140** by the turbo loader **150**. The turbo decoder **130** derives extrinsic values from the received encoded data signal. These extrinsic values are stored in the extrinsic RAMs **160** and made available during the iterations processed by the turbo decoder **130**. These so-called iterations can place heavy demands on the random access memory RAM **160** and may be performed by multiple turbo decoder engines within the turbo decoder **130**. During an iterative process the turbo decoder **130** improves the extrinsic values in the extrinsic RAMs, to arrive at a result for the transmitted bit. A conflict may occur if more than one decoder engine attempts to access the same extrinsic RAM **160** in the same cycle. Memory conflicts can lead to decoding data errors.

FIG. 2 illustrates a schematic block diagram of an exemplary turbo encoder **180** relating to embodiments. The turbo encoder **180** encodes processed data **105**. According to an embodiment, the turbo encoder uses two recursive systematic convolutional coders (RSC). In FIG. 2, two turbo encoder paths are illustrated, one path for a first recursive systematic convolutional coder (RSC) **230** and a second path for a second recursive systematic convolutional coder (RSC) **240**, coupled to a turbo code interleaver **220**. The interleaver **220** increases the probability that errors that cause a problem for one RSC, will not for the other. The interleaver **220** ensures this by spreading the data out in a defined manner. The interleaver **220** re-orders values within rows and columns of an interleaving matrix where interleaved values stay in a same re-ordered row. In embodiments of the present invention, rows can be defined as columns and columns defined as rows because the nature of a row or column is arbitrary. This may depend on the encoder for which as given decoder is designed.

Each of the first recursive systematic convolutional coder **230** and the second recursive systematic convolutional coder **240** have the illustrated series of three delays and four feedback and feed forward modulo 2 adders. The encoded data **195** output from the turbo encoder **180** includes x_k (the input processed data **105**), z_k (result of the first recursive systematic convolutional coder **230**), and $z'_{k'}$ (result of the second recursive systematic convolutional coder **240**). The encoded data **195** also may include $x'_{k'}$ which is used at the end of a processed data block to ensure the encoder ends in an all zero state.

The turbo encoder **180** encodes the processed data **105** to generate encoded data $[x_{k'}, z_{k'}, z'_{k'}]$ **195**. The turbo encoder **180** uses an interleaver **220** for interleaving the values of the processed data **105** (i.e., of the input sequence) within rows and columns of an interleaving matrix. In the interleaver **220**, the values of each row form a group and the values in each group stay within a same group. The interleaver **220** also re-orders the groups among rows and re-orders the values within a group.

FIG. 3 illustrates a schematic block diagram of the turbo decoder **130** and extrinsic RAMs **160** according to an exemplary embodiment of the present invention. During the decode process, the decoder **130** generates one extrinsic value for every bit of the processed data **105** that went into the encoder **180** originally. The turbo decoder **130** is responsible for reversing the interleaving process. To unwind the

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interleaving procedure, it may save power to generate the desired extrinsic values address in memory rather than move the data itself.

The turbo decoder **130** updates the extrinsic values each iteration. For each extrinsic value updated, one extrinsic value needs to be read and written. For high speed applications, a parallel architecture is used which may read and write multiple extrinsic values per cycle. The deinterleaver **360** may generate multiple addresses in parallel in order to read and write the extrinsic values. This may lead to memory conflicts if the correct memory architecture is not chosen. Memory conflicts can lead to decoding data errors. What is needed is a turbo decoder that avoids memory conflicts.

One problem addressed by the embodiments of the present invention is how to organize the extrinsic values in the extrinsic RAMs **160** without memory conflicts in these extrinsic RAMs **160** in a scalable parallel turbo decoder architecture without any loss of cycles or extra overhead. When extrinsic values are stored in the array of extrinsic RAMs **160**, there is a possibility of conflict on either a read or a write operation. Read and write conflicts can occur when more than one turbo decoder engine acts on the same RAM at the same time. It is trivial to guarantee no conflicts occur during the linear MAP estimates, however, it is difficult to ensure no read or write conflicts for both a linear and interleaved MAP estimate.

Embodiments of the present invention avoid conflicts when accessing the extrinsic RAMs **160** by multiple turbo decoder engines. Embodiments of the present invention are applicable to avoiding memory conflicts in turbo decoders for the 3rd Generation Partnership Project (3GPP) cellular specification as defined in 25.212 Section 4.2.3.2.3. Extrinsic values are generated by the turbo decoder **130** for use in future MAP estimates. The location in extrinsic RAM **160** cannot be moved between linear and interleaved MAP estimates. That is, a RAM architecture for extrinsic RAMs **160** is used that allows linear and interleaved access from the decoder engines to go to unique extrinsic RAMs **160**. The block of data to be decoded is broken up into sub-blocks. A sub-block of data is processed in parallel by decoder engines **340** acting on sub-blocks of the input data block. Each interleaved row is placed in a separate extrinsic RAM **160**. The sub-block size is chosen to ensure that each decoder engine is taking data from a different interleaved row during both the linear and interleaved MAP estimates. This organization of data in memory prevents the aforesaid problem of memory conflicts.

The turbo decoder **130** reads extrinsic values from extrinsic RAMs **160**, updates the extrinsic values so read, and then writes these updated extrinsic values back to the extrinsic RAMs **160**. This is done in both linear and interleaved order. In addition, it is done in parallel with a concurrent operation of N+1 decoder engines **340**. A conflict free address generator generates all extrinsic addresses and extrinsic rows per cycle.

The deinterleaver **360** generates the RAM Address (RA_m). This is the address in RAM **160** that the m^{th} decoder engine uses. The deinterleaver **360** also generates a RAM Number (RN_m). The RAM Number (RN_m) specifies which RAM **160** the m^{th} decoder engine uses data from. The extrinsic RAMs **160** are made up of 20 separate RAMs: RAM0 through RAM19 as illustrated in the embodiment of FIG. 3. These 20 extrinsic RAMs **160** are dual port RAMs, in an embodiment. There are also N+1 decoder engines **340** so $m=[0, \dots, N]$ inclusive. During even MAP estimates the linear address generator **310** creates RA_m and RN_m . During odd MAP estimates interleaved address generator **320** cre-

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ates the RA_m , and RN_m . The address multiplexer **330** selects between the two sources. The extrinsic reader unit **350** maps the address to the requested extrinsic RAM **160**, RAM **0** through RAM **19**. For example, if the deinterleaver **360** sets $RN_3=5$, and $RA_3=23$, then the extrinsic reader unit **350** would start a read from RAMS at address **23**. The data received from the read would go to the third decoder engine **340**, a.k.a. DECODER ENGINE **3**. The extrinsic reader unit **350** sends the read extrinsic signal (REX_3) to the correct decoder engine **340**. Extrinsic reader and writer units **350**, **370** take all extrinsic addresses and extrinsic rows to generate one RAM address for each individual extrinsic RAM **160**.

Each decoder engine then improves their extrinsic value and produces a write extrinsic signal (WEX_k). This write extrinsic signal WEX_k goes to the extrinsic writer unit **370** and gets mapped back to its original read location RN_k and RA_k . So the write extrinsic signal WEX_k gets written to the same extrinsic RAM **160** at the same address it was read from.

FIG. **4** illustrates example matrices of the interleaving process according to an exemplary embodiment of the present invention. A linear matrix **410** of 20×256 indices and an interleaved matrix **420** of 20×256 indices are illustrated. The numbers shown for the indices in the matrices of FIG. **4** are the bit indexes k used in the encoder from FIG. **2**. The job of an interleaver, such as the interleaver in the 3GPP cellular standards, is to mix up the data as it is going to transmit. It mixes up the data by putting the processed data **105** into a matrix going across each row as shown by the right arrow in matrix **410**. Then the rows are randomly interchanged. Also, the values within each row are re-ordered. Then the interleaved data is taken out going down each column as shown by the down arrow in matrix **420**.

Instead of filling the interleaving matrix with the processed data **105**, ascending bit indexes can be used (0, 1, 2, . . . , 5119) as shown in matrix **410**. Then after the interleaving procedure is applied by interchanging rows, and re-ordering values within each row, the interleaved matrix **420** is generated. The interleaved bit index can be obtained by reading the values going down each column from matrix **420**. Indexing the processed data **105** with these interleaved bit indexes will create the data sequence generated by the interleaver **220**, the same as if the processed data **105** was interleaved directly.

FIG. **5** illustrates the extrinsic RAM layout for the example case shown in FIG. **4**. All the values from the linear matrix **410** in FIG. **4** row 0, are in the first extrinsic RAM **0** (i.e., one of extrinsic RAMs **160**). The values from the second row 1, are in extrinsic RAM **1** (i.e., another one of extrinsic RAMs **160**). Using this mapping and carefully picking the spacing between decoder engines **340**, RAM conflicts can be avoided.

FIG. **6** illustrates a cycle by cycle operation of the turbo decoder **130** for the example of FIG. **4**. The table corresponds to an exemplary turbo decoder configured with two engines during a linear MAP estimate. Each line in the table corresponds to a decoder clock cycle. Values for decoder engine 0 start in row 0, column 0 of the matrices in FIG. **4**. For an exemplary cycle 1, the deinterleaver **360** would output $RA_0=0$, and $RN_0=0$. The extrinsic reader **350** outputs REX_0 equal to the extrinsic value corresponding to the 0th processed data bit **105** or E_0 . Values for decoder engine 1 start in row 1, column 0 of the matrices in FIG. **4**. For exemplary cycle 1, the deinterleaver **360** outputs $RA_1=0$, and $RN_1=1$. The extrinsic reader **350** would output REX_0 equal to the extrinsic value corresponding to the 256th

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processed data bit **105** or E_{256} . Both decoder engines operate across their respective rows. When the end of the row is reached, both decoder engines advance to the next row that requires processing, skipping any rows processed by other decoder engines. This decoder engine processing order guarantees that both decoder engines will never simultaneously be processing extrinsic values from the same row, and there will be no conflicts.

FIG. **7** illustrates a cycle by cycle operation of the turbo decoder **130** for the example of FIG. **4**. The table corresponds to an exemplary turbo decoder configured with two decoder engines during an interleaved MAP estimate. This is the interleaved MAP version of FIG. **6**. Each line in the table corresponds to a decoder clock cycle. Values for decoder engine 0 start in row 0, column 0 of the matrices in FIG. **4**. For an exemplary cycle, 1 the deinterleaver **360** outputs $RA_0=0$, and $RN_0=0$. The extrinsic reader **350** would output REX_{4865} equal to the extrinsic value corresponding to the 4865th processed data bit **105** or E_{4865} . Values for the decoder engine 1 start in row 1, column 1 of the matrices in FIG. **4**. For exemplary cycle 1, the deinterleaver **360** would output $RA_1=1$, and $RN_1=1$. The extrinsic reader **350** would output REX_0 equal to the extrinsic value corresponding to the 255th processed data bit **105** or E_{255} . Both decoder engines operate down their respective columns. When the end of the column is reached, the decoder engine advances to row zero of the next column. Once decoder engine 0 processes the extrinsic value just prior to the decoder engine 1 starting extrinsic value, both decoder engines skip over the already processes extrinsic values. This decoder engine processing order guarantees that both decoder engines will never be processing extrinsic values from the same row, and there will be no conflicts.

FIG. **8** illustrates a flow diagram of a process performed by a linear address generator according to an exemplary embodiment of the present invention. Given the exemplary embodiment of FIG. **3**, $N+1$ linear address generators **310** are disclosed, one for each decoder engine **340**, and the linear address generator **310** operates just during even MAP estimates when the extrinsic values are read in linear order. In the process illustrated in FIG. **8**, R represents a number of rows in the interleaver matrix **420**, C represents the number of columns in the interleaving matrix used by the turbo code internal interleaver **220**, RN represents RAM number, RA represents RAM address, and E represents decoder engine number.

An initial step **810** includes setting the RAM Number RN equal to the E , the decoder engine number for this instance of the linear address generator **310**. In step **820** the RAM Address RA is set to zero. In step **830** the RAM Address RA and RAM Number RN are output to the extrinsic RAMs **160**, for example, through the extrinsic reader **350** and the extrinsic writer **370**. In an example, the extrinsic reader **350** and extrinsic writer **370**, access RAM address RA from RAM number RN . The RAM Address RA is incremented by 1 in step **840** to move to the next column. The RAM Address RA continues incrementing until the RAM Address $RA=C$ columns in step **860**. When the RAM Address $RA=C$, flow proceeds to step **870**. In step **870**, the RAM Number RN is incremented by $N+1$ to skip over all the other instances of the linear address generator **310**. This is done until a determination is made that all rows have been processed at step **880**, at which time the method may end at step **890**. All rows have been processed when RN is greater or equal to R rows. Otherwise, when a determination is made in step **880** that more rows need processing, then flow returns to step **820**, at which the RAM Address RA is set to zero.

FIG. 9 illustrates a flow diagram of a process performed by the interleaved address generator 320 according to an exemplary embodiment of the present invention. The process illustrated generates addresses used to access the extrinsic RAMs 160 during odd MAP estimates. For odd MAP estimates, the extrinsic values are accessed in interleaved order. There are $N+1$ interleaved address generators, one for each decoder engine 340. $U_i(j)$ can be used for $U_{RN}(CC)$ in step 920 as the intra-row permutation pattern. $T(i)$ can be used for $T(RC)$ in step 960 and represent, for example, the inter-row permutation pattern defined in Section 25.212 of the 3GPP cellular specifications. In the FIG. 9, R represents a number of rows in the interleaver matrix 420, C represents the number of columns in the interleaving matrix used by the turbo code internal interleaver 220, CC represents column count, SC represents sub-block count, RN represents RAM number, and RA represents RAM address.

At the beginning of a turbo decoder MAP estimate, the row counter CC is initialized in step 915, the sub-block count SC 945 is initialized to zero in step 930, and the row counter is initialized in step 950. Address generation in interleaved mode is performed using the row count RC 955. Every cycle the row count 955 is incremented in step 965. This row count is translated by a $T(RC)$ table lookup in step 960, to generate the RAM number RN in step 975 and output to direct access to the extrinsic RAMs 160 by, for example, the extrinsic reader 350 and the extrinsic writer 370.

When RC equals R as determined in step 970, the column count CC is incremented in step 910 and RC is re-initialized at step 950. The column count CC 980 and RAM number RN are used as $U_{RN}(CC)$ in step 920 to look up the RAM address RA and output RA in step 925 to the extrinsic RAMs 160 through, for example, the extrinsic reader 350 and the extrinsic writer 370. In an example, the extrinsic reader 350 and extrinsic writer 370, access RAM address RA from RAM number RN . The sub-block count SC 945 is incremented every cycle in step 935, and is used to determine when the sub block ends. When a determination is made that the sub-block count 945 equals the preferred embodiment sub block size of 142 in step 940, it is the end of the sub-block, and the CC , SC and RC counters are initialized to be beginning of the next sub-block in steps 915, 930, and 950 respectively. The MAP estimate operation is complete when a determination is made that the column count CC equals C in step 905. Address generation in interleaved mode is performed using the column count CC 980.

While embodiments of the present invention address the problem of how to generate addresses with no memory conflicts on the extrinsic RAM in a scalable parallel turbo decoder architecture without loss of cycles or extra overhead for specifications such as the 3GPP cellular specifications, the present invention is applicable to other specifications now or in the future.

The interleaver of the turbo encoder can use a matrix representation with C columns and R rows, such as, for example, the interleaver defined in the 3GPP cellular specifications. Data bits to be interleaved are put into the matrix in the first row in column 0, 1, 2, . . . , $C-1$, then the second row and so on. Then the data bits are taken out of the matrix from the first column, from row 0, 1, 2, . . . , $R-1$, then the second column. The number of rows R can be 5, 10 or 20. The number of columns C can range from 8 to 256.

In order to undo the interleaving in the decoder, the turbo decoder reads the extrinsic values in interleaved order. After the decoder improves the extrinsic values, it then writes the extrinsic values to the same interleaved address. This is

equivalent to de-interleaving the extrinsic values, processing them, and re-interleaving them.

Embodiments of the present invention exploit characteristics of an interleaver, such as the interleaver in the 3GPP cellular specifications, to create an address generation algorithm that guarantees no extrinsic memory conflicts. In contrast, the interleaver in the 3GPP cellular specifications may allow memory conflicts to occur. According to an embodiment, each turbo block is broken into sub blocks of a predetermined size (L). A sub block size is chosen that allows each decoder engine to work on one row of the interleaver matrix without causing memory conflicts.

A radix-2 turbo decoder processes 1 extrinsic value per decoder engine per cycle. A radix-4 turbo decoder processes 2 extrinsic value per decoder engine per cycle. Multiple accesses to the same extrinsic RAM in the same cycle are guaranteed not to occur for radix-4 and radix-2 turbo decoders. Twenty dual port RAMs can be used to store the extrinsic values, one RAM for each interleaver row. This can scale to 20 radix-2 decoder engines or 10 radix-4 decoder engines. The turbo decoder can scale to beyond that in systems where there are more than twenty rows.

By way of example, consider the interleaving matrix shown in FIG. 4. Define E_k to be the k^{th} extrinsic value. The values shown in the matrices in FIG. 4 are the indexes k of the extrinsic values E_k . The sub block size is 256, and there are 2 decoder engines. For a radix-2 decoder doing an even MAP estimate, the turbo decoder will read/write the extrinsic values according to the table in FIG. 6. Values corresponding to each decoder engine are in a row associated with the decoder engine. For linear MAP estimates, the indexes fill a row first, so index 256 is in the second row. Since each extrinsic row has its own RAM, there are no conflicts.

For the same decoder doing an odd MAP estimate, assume the sub block size would be 21 (this is not practical, and is only used for illustration). The decoder will read/write the extrinsic values according to the table in FIG. 7. Values corresponding to each decoder engine are still a row associated with the decoder engine. For interleaved MAP estimates, the indexes fill the column first, so index 21 wraps around to row 1 column 1. Values corresponding to decoder engine 1 will always be one column ahead of values corresponding to decoder engine 0.

The approach used in the embodiments of the present invention takes advantage of the fact that the interleaver of the encoder re-orders the rows, and randomly re-orders the data within a row, but does not move data from one row to another. For even MAP estimates the sub block size is a multiple of C . For odd MAP estimates the preferred sub block size is 142. These sizes are chosen to allow each decoder engine to work on one row of the interleaver matrix without causing memory conflicts. For $K \leq 142$, only one decoder engine will be used and the sub block size is irrelevant. If the interleaving matrix contains dummy bits, such as, for example, the dummy bits defined in 3GPP cellular specification 25.212 Section 4.2.3.2.3.1, the decoder engine is idle for the cycle where an out of bounds address to this dummy bit or dummy entry is encountered. If the decoder engine is not idle, and skips over this dummy bit or dummy entry, it will jump ahead to the next interleaving row, and will eventually have conflicts with other decoder engines.

According to a further alternative embodiment, an address generator skips read of extrinsic values corresponding to dummy entries in the interleaving matrix. The linear address generator 310 and the interleaved address generator 320 in the embodiment of FIG. 3 save time and reduces conflicts

with write operations by knowing where the dummy entries are located and thus skip read steps for the extrinsic values corresponding to the locations for the dummy entries in the interleaving matrix. The address generators 310 and 320 in embodiments can still group the extrinsic values addressed for storage in the extrinsic addressable memories such that all the extrinsic values in each one of the rows go in a same one of the plurality of the extrinsic addressable memories. Also the address generators 310 and 320 in embodiments can still use a counter that skips read of extrinsic values corresponding to dummy entry addresses by continuing to count over the dummy entries in the interleaving matrix.

According to various embodiments, memory conflicts are avoided by allowing each row to be accessed by only one decoder engine. The algorithm also allows the deinterleaver to be designed in a way to guarantee that multiple accesses to the same extrinsic RAM do not occur at the same address in a radix-4 turbo decoder. This is accomplished by assuring each decoder engine has 2 unique rows. Finally, embodiments of the innovation may allow the turbo decoder to operate without any loss of cycles or extra overhead.

The turbo decoder in the embodiments of the present invention can be used by any methods or apparatus that use a 3GPP interleaver in the turbo encoding process such as Group System for Mobile communications (GSM), Universal Mobile Telecommunications System (UMTS) or High-Speed Downlink Packet Access (HSDPA).

An embodiment of a turbo decoder includes a plurality of turbo decoder engines, a plurality of extrinsic addressable memories, an extrinsic reader, an extrinsic writer, and a deinterleaver. The plurality of turbo decoder engines are for concurrently decoding a received signal encoded within rows and columns of an interleaving matrix where interleaved values stayed in a same re-ordered row during interleaving. The plurality of extrinsic addressable memories are operatively coupled to the turbo decoder engines and are to store extrinsic values used by the turbo decoder engines. The extrinsic reader is operatively coupled between the extrinsic addressable memories and the turbo decoder engines and is to access the extrinsic addressable memories using extrinsic addresses for accessing the extrinsic addressable memories. The extrinsic writer is operatively coupled between the extrinsic addressable memories and the turbo decoder engines to access the extrinsic addressable memories using the extrinsic addresses for accessing the extrinsic addressable memories. The deinterleaver is operatively coupled to the extrinsic reader and is to access the extrinsic addressable memories by arranging storage of the extrinsic values by the same rows of the same interleaving matrix that were used to encode the received signal, each of the rows corresponding to one of the plurality of turbo decoder engines.

According to a further embodiment, the deinterleaver groups the extrinsic values addressed for storage in the extrinsic addressable memories such that all the extrinsic values in each one of the rows of the interleaving matrix go in a same one of the plurality of the extrinsic addressable memories.

According to a further embodiment, the deinterleaver generates the extrinsic addresses for addressing the extrinsic addressable memories to access the extrinsic addressable memories and obtain the extrinsic values therefrom in the same rows of the same interleaving matrix that was used to encode the received signal.

According to a further embodiment, the deinterleaver includes a linear address generator operatively coupled to

extrinsic reader to generate the extrinsic addresses to read extrinsic values corresponding to one of the rows of the interleaving matrix at a time.

According to a further embodiment, the linear address generator includes a counter to generate the extrinsic addresses to read extrinsic values corresponding to one of the rows of the interleaving matrix at a time.

According to a further embodiment, the deinterleaver includes an interleaved address generator operatively coupled to extrinsic reader to generate the extrinsic addresses to read extrinsic values corresponding to one of the columns of the interleaving matrix at a time.

According to a further embodiment, the interleaved address generator includes a counter and a translation table location identified by the counter to generate the extrinsic addresses to read extrinsic values corresponding to one of the columns of the interleaving matrix at a time.

According to a further embodiment, the deinterleaver skips read of extrinsic values corresponding to dummy entries in the interleaving matrix.

According to a further embodiment, the counter skips read of extrinsic values corresponding to dummy entry addresses by continuing to count over the dummy entries in the interleaving matrix.

According to a further embodiment, the turbo decoder breaks the received signal into sub blocks of a size that allows each row of the interleaver matrix to correspond to one of the plurality of turbo decoder engines.

According to a further embodiment, the each one of the plurality of the extrinsic addressable memories includes a RAM.

An embodiment of a method of turbo decodes a received signal encoded within rows and columns of an interleaving matrix where interleaved values stayed in a same re-ordered row during interleaving. Parallel turbo decoding operations are concurrently performed on the received signal. Extrinsic values are stored in extrinsic addressable memories used by the turbo decoding. The extrinsic addressable memories are read accessed using extrinsic addresses for accessing them. The extrinsic addressable memories are write accessed using the extrinsic addresses for accessing them. Deinterleaving is performed to access the extrinsic addressable memories by arranging storage of the extrinsic values by the same rows of the same interleaving matrix that was used to encode the received signal. Each of the rows accessed correspond to one of the concurrent turbo decoding operations.

According to a further embodiment, the deinterleaving groups the extrinsic values addressed for storage in the extrinsic addressable memories such that all the extrinsic values in each one of the rows of the interleaving matrix go in a same one of the plurality of the extrinsic addressable memories.

According to a further embodiment, the deinterleaving generates the extrinsic addresses for addressing the extrinsic addressable memories to access the extrinsic addressable memories and obtain the extrinsic values therefrom in the same rows of the same interleaving matrix that was used to encode the received signal.

According to a further embodiment, the deinterleaving linearly generates the extrinsic addresses to read extrinsic values corresponding to one of the rows of the interleaving matrix at a time.

According to a further embodiment, counting generates the extrinsic addresses to read extrinsic values corresponding to one of the rows of the interleaving matrix at a time.

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According to a further embodiment, the deinterleaving interleaves the extrinsic addresses to read extrinsic values corresponding to one of the columns of the interleaving matrix at a time.

According to a further embodiment, counting and identifying a location in a translation table identified by the counting generates the extrinsic addresses to read extrinsic values corresponding to one of the columns of the interleaving matrix at a time.

According to a further embodiment, the deinterleaving skips read of extrinsic values corresponding to dummy entries in the interleaving matrix.

According to a further embodiment, the counting skips read of extrinsic values corresponding to dummy entry addresses by continuing to count over the dummy entries in the interleaving matrix.

According to a further embodiment, the concurrently performed parallel turbo decoding operations on the received signal breaks the received signal into sub blocks of a size that allows each row of the interleaver matrix to correspond to one of the plurality of turbo decoding operations.

An embodiment of an encoding and decoding system includes a turbo encoder and a turbo decoder. The turbo encoder encodes an input sequence of values to generate an encoded signal, the turbo encoder includes an interleaver that uses a predetermined interleaving sequence to interleave the values of the input sequence within rows and columns of an interleaving matrix with the values of each row form a group, wherein the values in each group stay within a same group. The turbo decoder includes a plurality of turbo decoder engines, a plurality of extrinsic addressable memories, an extrinsic reader, an extrinsic writer, and a deinterleaver. The plurality of turbo decoder engines are for concurrently decoding a received signal encoded within rows and columns of an interleaving matrix where interleaved values stayed in a same re-ordered row during interleaving. The plurality of extrinsic addressable memories are operatively coupled to the turbo decoder engines and are to store extrinsic values used by the turbo decoder engines. The extrinsic reader is operatively coupled between the extrinsic addressable memories and the turbo decoder engines and is to access the extrinsic addressable memories using extrinsic addresses for accessing the extrinsic addressable memories. The extrinsic writer is operatively coupled between the extrinsic addressable memories and the turbo decoder engines to access the extrinsic addressable memories using the extrinsic addresses for accessing the extrinsic addressable memories. The deinterleaver is operatively coupled to the extrinsic reader and to generate the extrinsic addresses for accessing the extrinsic addressable memories by arranging storage of the extrinsic values in a way that avoids extrinsic memory conflicts such that each of the turbo decoder engines uses extrinsic values corresponding to one of the rows of the interleaving matrix that was used to encode the encoded signal.

According to a further embodiment, the interleaver re-orders the groups among rows and re-orders the values within a group.

An embodiment of a turbo decoder includes a plurality of turbo decoder engines, a plurality of extrinsic addressable memories, an extrinsic reader, an extrinsic writer, and an address generator. The plurality of turbo decoder engines are for concurrently decoding a received signal encoded within rows and columns of an interleaving matrix where interleaved values stayed in a same re-ordered row during interleaving. The plurality of extrinsic addressable memo-

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ries are operatively coupled to the turbo decoder engines and are to store extrinsic values used by the turbo decoder engines. The extrinsic reader is operatively coupled between the extrinsic addressable memories and the turbo decoder engines and is to access the extrinsic addressable memories using extrinsic addresses for accessing the extrinsic addressable memories. The extrinsic writer is operatively coupled between the extrinsic addressable memories and the turbo decoder engines to access the extrinsic addressable memories using the extrinsic addresses for accessing the extrinsic addressable memories. The address generator is operatively coupled to the extrinsic reader and is to access the extrinsic addressable memories by the same rows of the same interleaving matrix that were used to encode the received signal and skip read of extrinsic values corresponding to dummy entries in the interleaving matrix.

According to a further embodiment, the address generator comprises a counter that skips read of extrinsic values corresponding to dummy entry addresses by continuing to count over the dummy entries in the interleaving matrix.

According to a further embodiment, each of the rows correspond to one of the plurality of turbo decoder engines.

According to a further embodiment, the address generator groups the extrinsic values addressed for storage in the extrinsic addressable memories such that all the extrinsic values in each one of the rows go in a same one of the plurality of the extrinsic addressable memories.

The signal processing techniques disclosed herein with reference to the accompanying drawings can be implemented on one or more digital signal processors (DSPs) or other microprocessors. Nevertheless, such techniques could instead be implemented wholly or partially as hardwired circuits. The RAM could refer to a physical RAM instance in silicon, or a buffer in a DSP. Further, it is appreciated by those of skill in the art that certain well known digital processing techniques are mathematically equivalent to one another and can be represented in different ways depending on choice of implementation.

Although the invention is described herein with reference to specific embodiments, various modifications and changes can be made without departing from the scope of the present invention as set forth in the claims below. Accordingly, the specification and figures are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of the present invention. They can have different configurations than the examples illustrated in the drawings. Any benefits, advantages, or solutions to problems that are described herein with regard to specific embodiments are not intended to be construed as a critical, required, or essential feature or element of any or all the claims.

Any letter designations such as (a) or (b) etc. used to label steps of any of the method claims herein are step headers applied for reading convenience and are not to be used in interpreting an order or process sequence of claimed method steps. Any method claims that recite a particular order or process sequence will do so using the words of their text, not the letter designations.

Unless stated otherwise, terms such as “first” and “second” are used to arbitrarily distinguish between the elements such terms describe. Thus, these terms are not necessarily intended to indicate temporal or other prioritization of such elements.

What is claimed is:

1. A turbo decoder comprising:

a plurality of turbo decoder engines configured to concurrently decode a received signal encoded within rows

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and columns of an interleaving matrix where interleaved values stayed in a same re-ordered row during interleaving;

a plurality of extrinsic addressable memories operatively coupled to the turbo decoder engines and configured to store extrinsic values used by the turbo decoder engines for the decoding;

an extrinsic reader operatively coupled between the extrinsic addressable memories and the turbo decoder engines and configured to read from the extrinsic addressable memories using extrinsic addresses for accessing the extrinsic addressable memories; and

an extrinsic writer operatively coupled between the extrinsic addressable memories and the turbo decoder engines and configured to write to the extrinsic addressable memories using the extrinsic addresses for accessing the extrinsic addressable memories; and

a deinterleaver operatively coupled to the extrinsic reader and configured to access the extrinsic addressable memories by arranging storage of the extrinsic values by the same rows of the same interleaving matrix, which same rows were previously used to encode the received signal, and each of the same rows corresponds to one turbo decoder engine of the plurality of turbo decoder engines.

2. A turbo decoder according to claim 1, wherein the deinterleaver is configured to group the extrinsic values addressed for storage in the extrinsic addressable memories such that all the extrinsic values in each one of the rows of the interleaving matrix go in a same one of the plurality of the extrinsic addressable memories.

3. A turbo decoder according to claim 1, wherein the deinterleaver is configured to generate the extrinsic addresses for addressing the extrinsic addressable memories and is configured to access the extrinsic addressable memories and obtain the extrinsic values therefrom in the same rows of the same interleaving matrix that was used to encode the received signal.

4. A turbo decoder according to claim 3, wherein the deinterleaver comprises a linear address generator operatively coupled to the extrinsic reader and is configured to generate the extrinsic addresses to read extrinsic values corresponding to one of the rows of the interleaving matrix at a time.

5. A turbo decoder according to claim 4, wherein the linear address generator comprises a counter configured to generate the extrinsic addresses to read extrinsic values, the extrinsic values corresponding to one of the rows of the interleaving matrix at a time.

6. A turbo decoder according to claim 4, wherein the deinterleaver comprises an interleaved address generator operatively coupled to the extrinsic reader and configured to generate the extrinsic addresses to read extrinsic values corresponding to one of the columns of the interleaving matrix at a time.

7. A turbo decoder according to claim 6, wherein the interleaved address generator comprises a counter and a translation table, wherein the interleaved address generator is configured for the counter to identify a location in the translation table and generate the extrinsic addresses to read extrinsic values corresponding to one of the columns of the interleaving matrix at a time.

8. A turbo decoder according to claim 7, wherein the deinterleaver is configured to skip read of extrinsic values corresponding to dummy entries in the interleaving matrix; and

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wherein the counter is configured to skip read of extrinsic values corresponding to dummy entry addresses by being further configured to continue to count over the dummy entries in the interleaving matrix.

9. A turbo decoder according to claim 1, wherein the turbo decoder is configured to break the received signal into sub blocks of a size that allows each row of the interleaver matrix to correspond to one of the plurality of turbo decoder engines.

10. A method of turbo decoding, the method comprising:

- concurrently performing parallel turbo decoding operations on a received signal, wherein the received signal was encoded within rows and columns of an interleaving matrix where interleaved values stayed in a same re-ordered row during interleaving;
- storing extrinsic values in extrinsic addressable memories used by the turbo decoding of said step (a);
- read accessing the extrinsic addressable memories using extrinsic addresses for accessing the extrinsic addressable memories;
- write accessing the extrinsic addressable memories using the extrinsic addresses for accessing the extrinsic addressable memories; and
- deinterleaving to access the extrinsic addressable memories by arranging storage of the extrinsic values by the same rows of the same interleaving matrix that was used to encode the received signal, each of the rows corresponding to one of the concurrent turbo decoding operations of said step (a).

11. A turbo decoder according to claim 10, wherein said step (e) of deinterleaving groups the extrinsic values addressed for storage in the extrinsic addressable memories such that all the extrinsic values in each one of the rows of the interleaving matrix go in a same one of the plurality of the extrinsic addressable memories.

12. A method of turbo decoding according to claim 10, wherein said step (e) of deinterleaving generates the extrinsic addresses for addressing the extrinsic addressable memories to access the extrinsic addressable memories and obtain the extrinsic values therefrom in the same rows of the same interleaving matrix that was used to encode the received signal.

13. A method of turbo decoding according to claim 12, wherein said step (e) of deinterleaving comprises the sub step of (e)(1) linearly generating the extrinsic addresses to read extrinsic values corresponding to one of the rows of the interleaving matrix at a time; and wherein the substep of (e)(1) comprises a substep of (e)(1)(i) counting to generate the extrinsic addresses to read extrinsic values corresponding to one of the rows of the interleaving matrix at a time.

14. A method of turbo decoding according to claim 12, wherein said step (e) of deinterleaving comprises the sub steps of:

- (e)(1) linearly generating the extrinsic addresses to read extrinsic values corresponding to one of the rows of the interleaving matrix at a time; and
- (e)(2) interleaving the extrinsic addresses to read extrinsic values corresponding to one of the columns of the interleaving matrix at a time.

15. A method of turbo decoding according to claim 10, wherein said step (e) of deinterleaving comprises the sub step of (e)(1) skipping read of extrinsic values corresponding to dummy entries in the interleaving matrix by continuing to count over the dummy entries in the interleaving matrix.

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16. A method of turbo decoding according to claim 10, wherein said step (a) of concurrently performing parallel turbo decoding operations on the received signal breaks the received signal into sub blocks of a size that allows each row of the interleaver matrix to correspond to one of the plurality of turbo decoding operations. 5

17. A turbo decoder comprising:

a plurality of turbo decoder engines configured to concurrently decode a received signal encoded within rows and columns of an interleaving matrix where interleaved values stayed in a same re-ordered row during interleaving; 10

a plurality of extrinsic addressable memories operatively coupled to the turbo decoder engines and configured to store extrinsic values used by the turbo decoder engines for the decoding; 15

an extrinsic reader operatively coupled between the extrinsic addressable memories and the turbo decoder engines and configured to read from the extrinsic addressable memories using extrinsic addresses for accessing the extrinsic addressable memories; and 20

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an address generator operatively coupled to the extrinsic reader and configured to access the extrinsic addressable memories by the same rows of the same interleaving matrix, which same rows were previously used to encode the received signal, and wherein the address generator is additionally configured to skip read of extrinsic values corresponding to dummy entries in the interleaving matrix.

18. A turbo decoder according to claim 17, wherein the address generator comprises a counter that skips read of extrinsic values corresponding to dummy entry addresses by continuing to count over the dummy entries in the interleaving matrix.

19. A turbo decoder according to claim 17, wherein each of the rows corresponds to one of the plurality of turbo decoder engines.

20. A turbo decoder according to claim 17, wherein the address generator groups the extrinsic values addressed for storage in the extrinsic addressable memories such that all the extrinsic values in each one of the rows go in a same one of the plurality of the extrinsic addressable memories.

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